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EQUIPMENT AND TRACKING TEST RESULTS FOR THE NRL SHIP-TO- SHIP D--ETC(U)  
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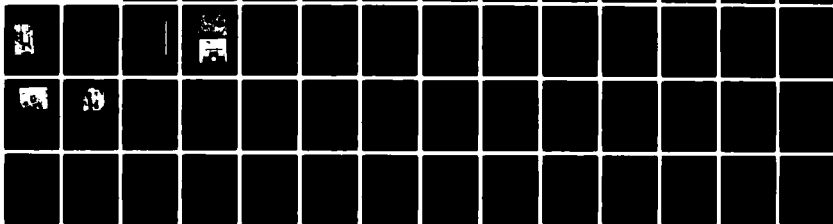
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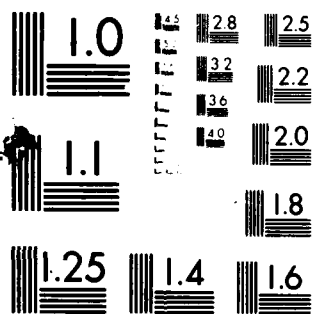
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# Equipment and Tracking Test Results for the NRL Ship-to-Ship DF Laser Transmission Experiment

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## **EQUIPMENT AND TRACKING TEST RESULTS FOR THE NRL SHIP-TO-SHIP DF LASER TRANSMISSION EXPERIMENT**

### **INTRODUCTION**

In this project the primary goal is to make atmospheric transmittance measurements over water at sea. The measurement will occur between two ships, one the USS LEXINGTON and the other an escort ship yet to be identified. Figure 1 is an artist's conception of the experiment in progress.

To do this experiment in the light-in-the-bucket approach that has proven so successful in the past, it is necessary that the light source and the receiving "bucket" reciprocally track each other. Thus, a major portion of the project deals with the design and construction of the trackers and their associated optics and servo systems. Many other aspects are also important and will be at least briefly described here.



**Fig. 1 — Ship-to-ship experiment**

Manuscript submitted March 8, 1982.

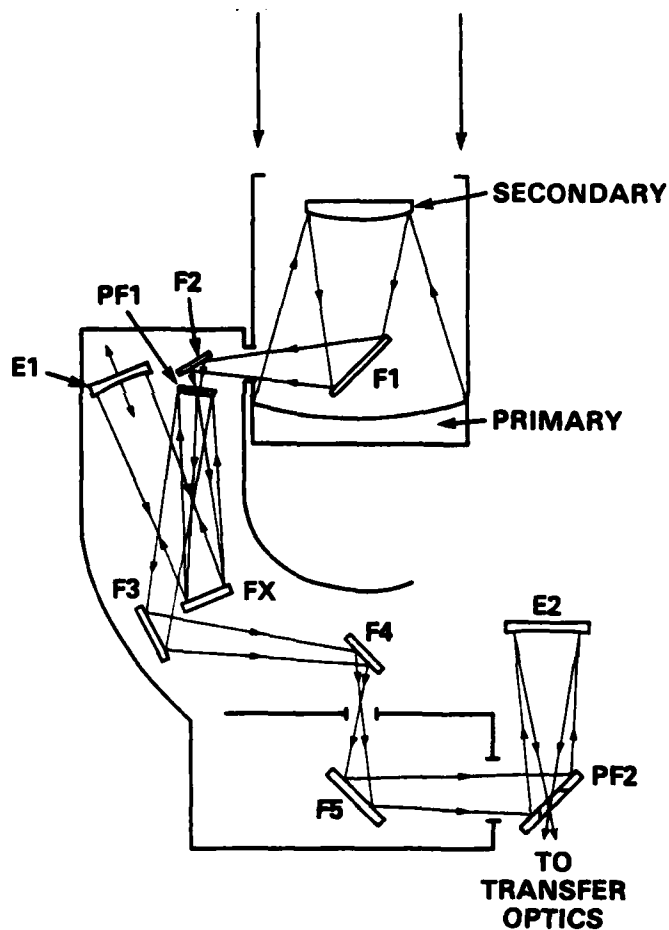
As an intermediate milestone we were to demonstrate the required  $50 \mu\text{rad}$  tracking capability under a simulated ship motion. This report describes the results of that milestone demonstration. It also describes the rest of the system in its current state and some programmatic aspects of arranging for the experiment aboard the ships.

## TRACKER OPTICS

For nomenclature purposes we have divided the optical system into two parts: the tracker optics, and the transfer optics. The purpose of the combined system is twofold. During operation of the DF laser the transfer optics up-collimates the laser radiation ( $3.8 \mu\text{m}$ , 50 mW), combines it colinearly with a HeNe laser beam ( $.63 \mu\text{m}$ , 15 mW), and transfers the beam into the tracker optics. Here the radiation passes through three intermediate foci and finally out through the 32" diameter,  $f/6$  Cassegrain telescope mounted in the Nike/Hercules mount. During the other mode of operation the tracker captures incoming radiation and directs it through the relay system and transfer optics and into the entrance aperture of the Fourier Transform Spectrometer (FTS). When viewing a blackbody radiation source this mode will provide high resolution spectral data at  $2\text{--}12 \mu\text{m}$  wavelength. We describe the tracker optical system in this section, and a discussion of the transfer optics is given in the following section.

Figure 2 is a schematic of the tracker optical system. The drawing is not to scale, and several optical paths have been rotated out of plane for clarity, but all components are shown. Mirrors F1, F2, F3, F4, F5, and FX are flats. Mirrors PF1 and PF2 are perforated flats, i.e., flats with a central hole bored out through which a focussed beam may pass. The Cassegrain telescope components consists of the 32",  $f/2.5$  parabola (weight about 400 lbs), and a matched 13.5" hyperbola. In the original design E1 and E2 were ellipses with identical radii of curvature, but we decided that E1 could be replaced with a sphere with a substantial savings in cost. Also, use of a sphere at E1 reduces the required alignment precision for minimal off-axis aberrations. E2 remains an ellipse. Flat FX was added to the original design in order to fold the path inside the mount yoke. The sphere E1 is adjustable, allowing the system to focus on objects at less than infinite distance. The output of the tracker optics is the final focus

Fig. 2 — Tracker optics schematic



at the center of perforated flat PF2. This point is regarded as the input port to the transfer optics. Figure 3 shows the tracker with optics mounted. The mirrors send the beam down through the inside of the left half of the yoke as viewed. The TV monitor is seen mounted on the end of the right trunnion.

We now provide a brief "walk-thru" description of an incoming beam. Incoming light is reflected from the primary to the secondary (area obscuration ratio 17%) to turning flats F1 and F2 and brought to the 1st focus at the center of PF1. This comprises an  $f/6$  telescope. The beam expands off FX to E1 which slows the beam of  $f/18$  and puts the next focus at the center of the azimuth axis, after undergoing five more flat reflections, as shown. The hole size in the perforated flats has been chosen to match the original 17% obscuration, so no needless loss of beam energy occurs. At this stage careful adjustment insures that the 2nd focus is exactly centered on the azimuth axis so no image *translation*



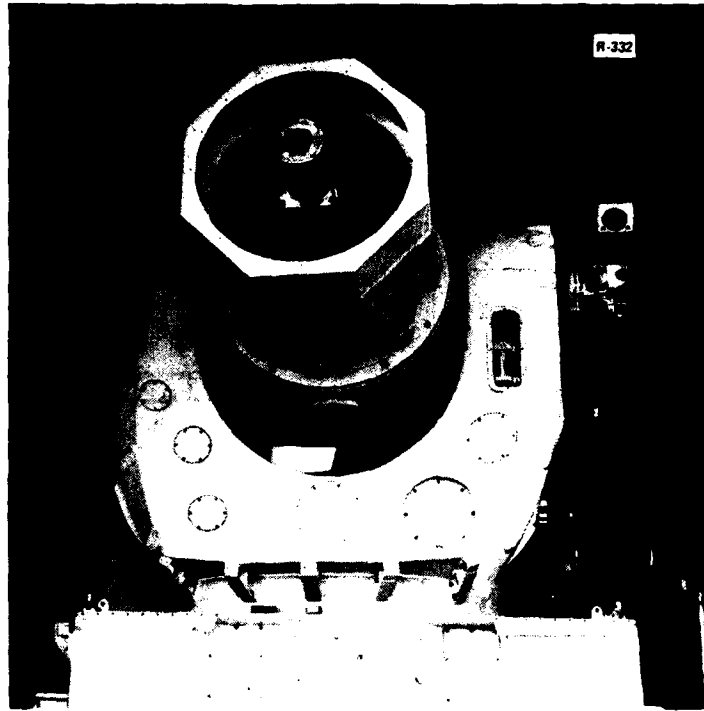


Fig. 3 — Tracker with optics installed

occurs when the mount rotates. Flat F5 directs the beam off the central axis, at  $f/18$ . Ellipse E2 is placed in such a manner that the beam is returned to the original  $f/6$  of the Cassegrain. Since E1 and E2 are both radius of curvature 54", the Cassegrain image at PF1 is transferred to PF2 at 1:1 and  $f/6$ .

All components of the tracker optics are in place and a preliminary alignment has been completed. A preliminary measurement indicates a 0.4 degree (full) field-of-view.

#### TRANSFER OPTICS

The purpose of the transfer optics is to couple the DF laser source to the tracker optics, and to couple incoming blackbody radiation to the FTS entrance aperture. Rotation of a turning flat enables a change from one mode to the other. The FTS input aperture requires a well-collimated 2" diameter beam. Since the DF and HeNe beams are easily manipulated, the 2" diameter, collimated beam requirement was the design goal of the transfer optics system.

Figure 4 describes the transfer optics design. As with the tracker optics drawing, the schematic is not to scale and some liberty has been taken with rotation of optical planes so a two dimensional drawing would be possible. The transfer optics will sit on a bench above tracker optics mirror E2 and PF2, but also attached to the tracker optical system, not to the trailer body. The system consists of transfer flats TF1 through TFS5, transfer perforated flat TPF1, beamsplitter TBS1, parabola P1, and spheres S1 and S2.

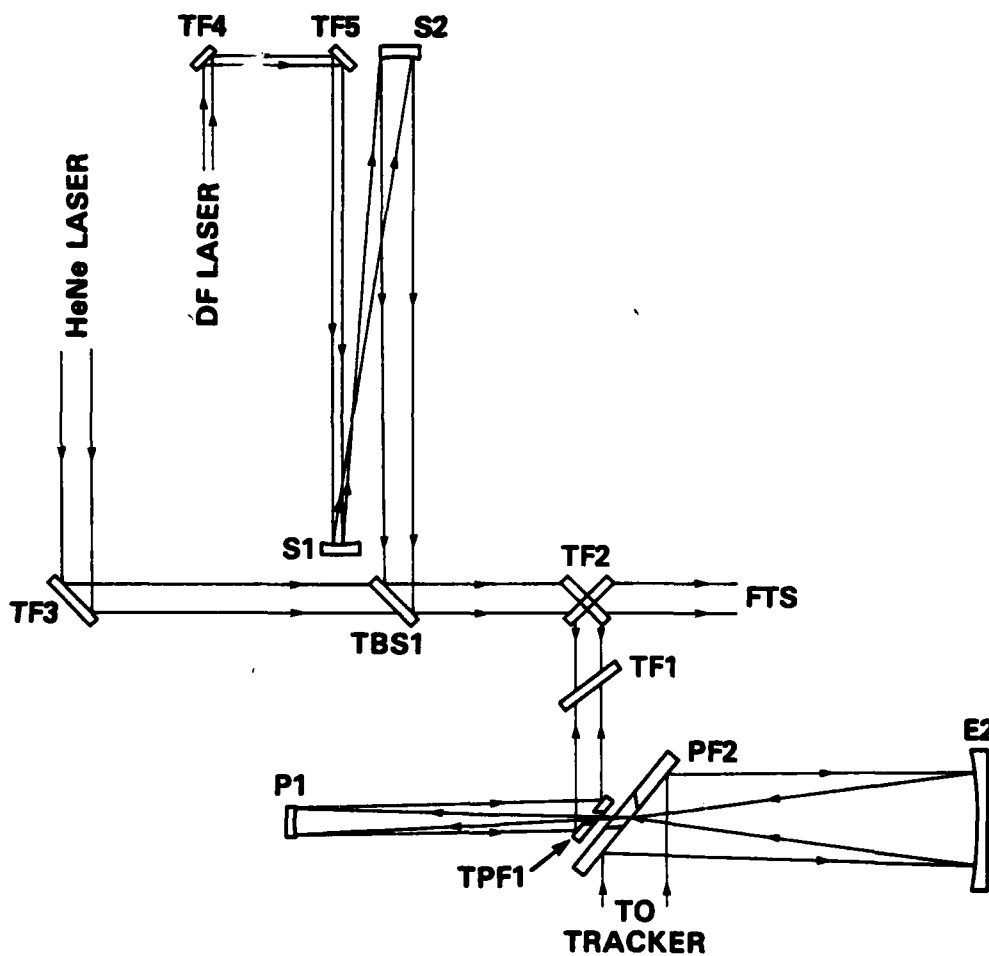


Fig. 4 - Transfer optics schematic

We now walk through the system beginning at the DF laser output. The optical cavity of the DF laser is an unstable resonator, and its output is allowed to diverge into the up-collimating telescope formed by the spheres S1 and S2. The DF beam, now 2" in diameter and collimated, is combined with the 2" collimated HeNe laser beam at dichoric beam splitter TBS1. TF2, TF1, and TPF1 direct the beam onto the f/6 parabola P1. From here the f/6 beam is coupled into the previously described f/6 tracker optics system through PF2. An optical chopper will be placed between TF4 and TF5 to provide modulation for the laser extinction measurement. During FTS operation TF2 will be rotated to direct the incoming beam into the FTS. As in the tracker optics, the obscuration ratio in TPF1 has been chosen to match the Cassegrain obscuration.

The components of the transfer optics are now being constructed, and delivery is expected by 1 March 1982.

#### SHIP MOTION

Data used in tracking amplitude calculations were obtained from the following sources.

1. *Summary of Synoptic Meteorological Observations*, Vol. 4, Area 23.
2. Naval Meteorological office at Key West.
3. NAVSEASYS COM Code 3213 *Hull Form Design/Performance/Stability*.

The hull design group was most helpful in obtaining computer generated data on ship motion of roll, heave, and pitch. Unfortunately, such data on the USS LEXINGTON was unavailable. However, an acceptable approximation to this data is that for the USS TARAWA (LHA1). For these calculations, the escort ship assumed is of the Forest Sherman class (DD931).

#### TARAWA (LHA1)

Dis. — 38,500 t

Length — 778 ft

Beam — 106 ft

LEXINGTON (CVT 16)

Dis. — 41,000 t

Length — 889 ft

Beam — 192 ft

FOREST SHERMAN (DD 931)

Disp. — 4000 t

Length — 407 ft

Beam — 47.5 ft

Assumptions made prior to the Tracking Amplitude Calculations are as follows:

1. Ship speed 10-20 knots.
2. Seas are short-crested and wind driven with a period  $T = 5$  to 10 sec.
3. For pitch measurements: the 60" searchlight is situated 40 m from the center of gravity (CoG) of the escort ship, the tracker is situated 70 m from the CoG of the LEXINGTON.
4. For roll measurements: the tracker and 60" searchlight are situated at the inboard gunwhale of their respective ships.
5. Heave and pitch are assumed independent of wave direction. Roll is largely dependent on wave direction.
6. Roll, heave and pitch are assumed linear with sea state.

Typically, the period of the largest movement (roll) is on the order of 15 sec, and that of the smallest movement (pitch) is about 7 seconds.

In calculating the Cumulative Tracking Amplitude the only data used which is independent of the distance between the ships is the roll angle of the LEXINGTON (the transmitter). The pitch and heave of both ships as well as the roll angle of the escort ship (receiver) were all converted to angular amplitude using a ship-to-ship distance of 1 km. *This determines the maximum elevation angle through which the transmitter must rotate in order to keep the beam on target.* These maximum angles are given in Fig. 5 for the three cases of head-seas, following-seas, and seas-abeam as a function of sea state, or wave height. All tracking operations will take place during periods of head or following seas. The case of seas-abeam is only presented to show an upper limit on necessary tracking amplitude for operations in the Gulf of Mexico.

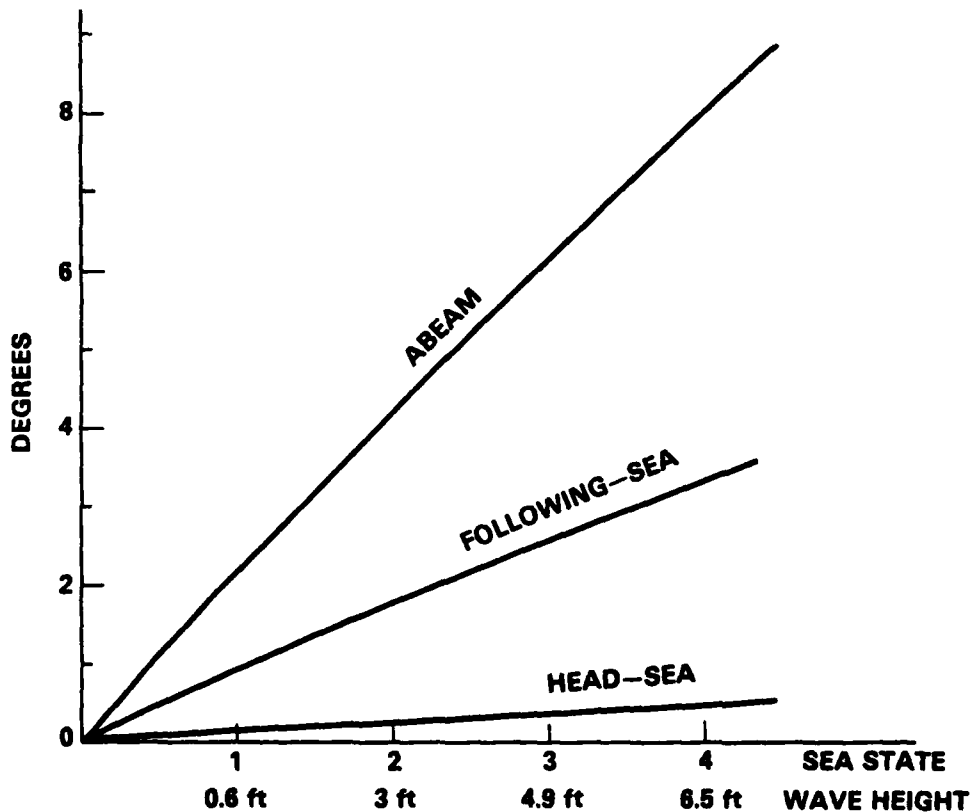


Fig. 5 - Cumulative tracking amplitude at 1 km range

## WEATHER

Weather and sea state conditions, and forecasts for the Gulf of Mexico, may be obtained by contacting the following Naval Meteorological offices:

1. Key West (AV) 483-2423
2. Pensacola (AV) 922-3644.

General weather and sea state trends have been determined from weather data obtained over the period 1951-1971 and are presented in *Summary of Synoptic Meteorological Observations*, Naval Oceanography Command Detachment, Vol. 4, Area 23.

## TRACKER TEST RESULTS

We now describe a series of tests made on the tracker servo-system. We had originally planned to put the tracker on the pitch-and-roll platform at NRL's Chesapeake Bay Division (CBD) facility, but a number of considerations, including bad weather, required us to perform the tests inside a large shop at CBD. Before describing the tests and results we first give a brief review of the system requirements.

As shown in the Ship Motion section, a cumulative amplitude of 0.5 deg (sea state 4) at about a 12 second period results during head-sea operation. Head-sea operation will be the only time when the tracker system will be in operation. Since the yaw amplitude is negligible during head-sea motion, azimuth control is far less stringent than elevation control. Within the 0.5 degree amplitude we need better than 150  $\mu\text{rad}$  precision ( $\pm 75 \mu\text{rad}$ ). This is the required precision to keep a 30" collimated beam within a 60" diameter receiver at 5 km range. As we have discussed previously, (D. H. Leslie, P. B. Ulrich, G. L. Trusty, "Technical Analysis of a Proposed Ship-to-Ship Chemical Laser Transmission Experiment", NRL Memorandum Report 4745), the turbulence effect on the 30" beam is less than 10  $\mu\text{rad}$  with  $C_n^2 = 10^{-14} \text{ m}^{-2/3}$ . This part of the experiment concerns the DF laser absolute transmittance measurement, from LEXINGTON to the escort ship. The tracking requirements for the return-path FTS spectral measurements are far less demanding (0.5 deg, or 8.7 mrad). Thus the goal of the present tests was to measure how much better than 150  $\mu\text{rad}$  the tracking elevation could perform, when roll simulations of greater than 0.5 deg were applied.

Since bad weather and other conditions prevented outdoor tests, we employed a 77-foot path inside the main shop at CBD. Two separate tests were performed. The first involved simulating the roll of the ship by driving one leg of the three-leg tracker support up and down through a 3" amplitude. We did this using a 1/2" reversible hand drill on the jacking mechanism of the tripod leg. Figure 6 shows the procedure.



Fig. 6 — Procedure for driving tripod to simulate ship motion

A 3" amplitude simulates a 1.7 deg roll (30 mrad). Since the heave of the escort ship at 1 km range will contribute 2 mrad or less (sea state 4) to the tracking requirement, motion of the GaAs beacon was not required. The GaAs beacon was placed 72' from the tracker, at about -5 deg elevation. A target for the TV camera was placed on the wall at 77', with 1/8" and 1/4" marks. (1/8" at 77' is 135  $\mu$ rad). The TV camera, mounted on the elevation trunnion and hence locked to the tracker telescope,

recorded the net effect of the roll motion plus the tracker's compensation on videotape. The motor drive for the roll simulation was not at all smooth, and a saw-tooth with superimposed jerks was the input drive. The tracker performed well, but had some problems with the transients. The ship's motion will not be at all like the input to this test, but will be much more like a sine wave. The conclusion from this first part of the test was that the system performed within the requirements, under very demanding conditions.

A second test was performed under more realistic conditions. A 0.5 deg equivalent amplitude motion was given to the elevation drive by injecting a 0.08 Hz signal into the drive train. The servo-system was turned on, with the quad cell looking at the GaAs beacon. The system gain was increased in steps and the resultant motion as indicated by the quad cell was recorded.

Figure 7 shows the reduction in errors as the gain magnitude is varied from 0.2 to 10 times its nominal setting. One can see that in the small signal regime the gain can be increased by a factor of 4 before instability results at a gain increase of 10 X nominal. At any rate, the  $35 \pm 35 \mu\text{rad}$  errors with the drill test could be reduced by a factor of at least 2 and possibly 4.

The large-signal Bode plot is pessimistic about stability as evidenced by these results. Since it is anticipated that an elevation (EL) tach loop more nearly like the azimuth (AZ) tach loop will be obtained in the near future, one can look forward to further improvements in the position loop allowing both  $20\text{-}\mu\text{rad}$  errors and comfortable stability margins.

A series of static tests were also performed. The operator in Fig. 8 is seated in front of the tracker control panel. His left hand is on the joy-stick as he views the TV monitor displaying the output of the trunnion-mounted telephoto TV camera. In operation the seat and control box unit will sit attached to the top of the hydraulic scissors jack against the wall in the right background. The operator will raise himself up to a position where his head sticks through an opening in the roof for unobstructed viewing. Figure 9 is a close-up of the control panel (still in its checkout condition). The trackball is obvious in the bottom center. The left digital switches and displays are for azimuth, the right for elevation.



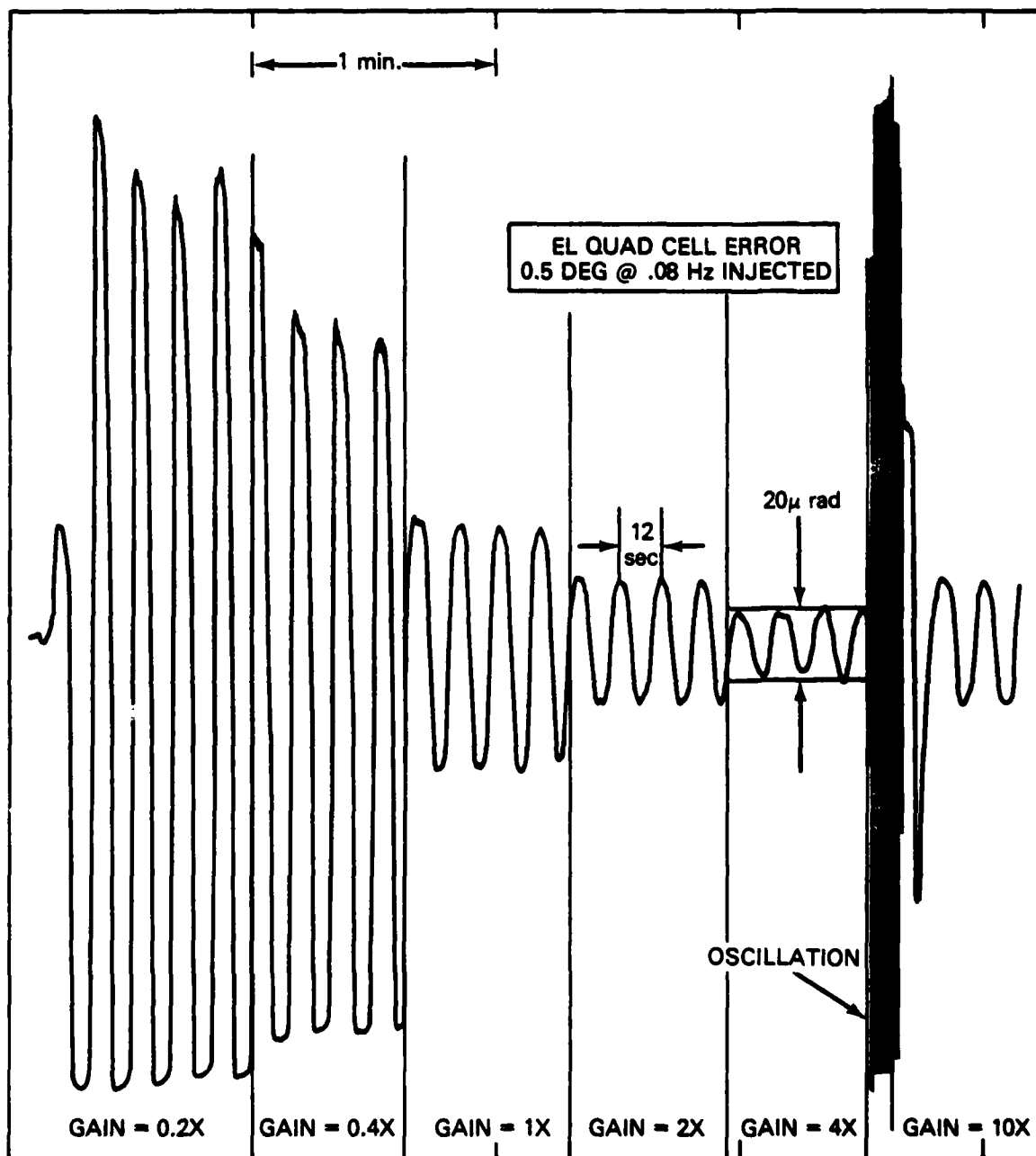


Fig. 7 - Quad-cell error as a function of feedback gain magnitude

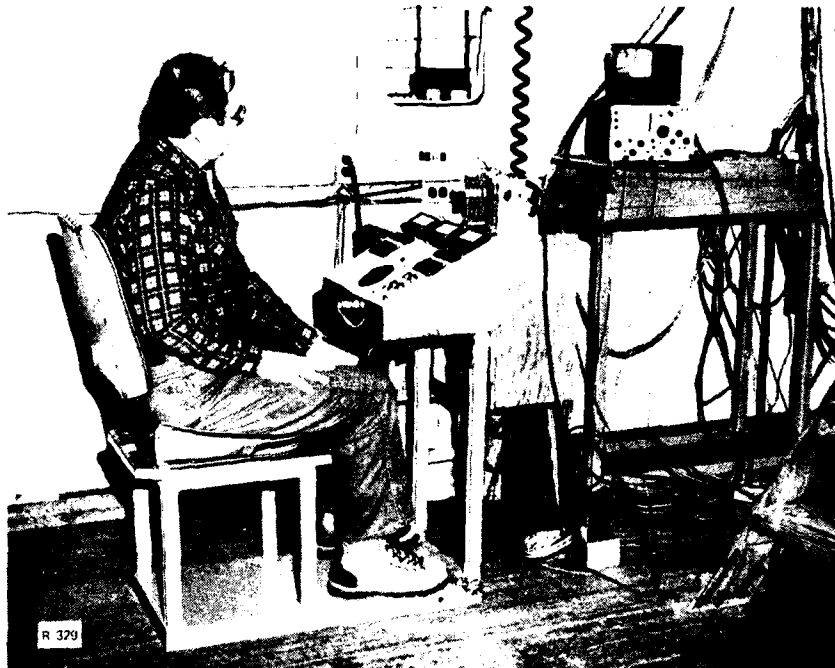


Fig. 8 — Operator control station

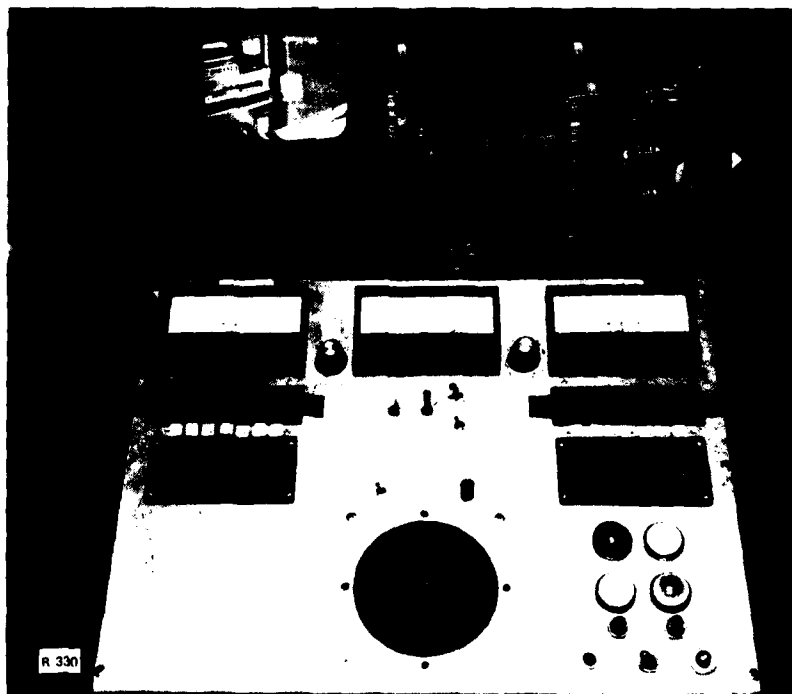


Fig. 9 — Operator control panel

The right half of the split screen monitor shows a building 317 m away as seen by the trunnion mounted TV camera. Using the brick pattern as a target for the static control test, we determined that one units digit change of the thumbwheel switch did, indeed, give a repeatable  $50 \mu\text{rad}$  position control in both axes. Note the overwritten date and time on the screen. This and the split-screen capability will be discussed further in the Communications System Section.

Another test was performed to examine turbulence effects of the GaAs beacon. Although the system performed well indoors at 22 meter range, when the beacon was placed on the roof of a building 208 meters away, the GaAs signal was too weak to acquire the lock. As substantiated by the video recordings at 208 meter range, turbulence effects are important on the 2" diameter aperture. Hence we plan to increase the quad-cell receiver aperture, and decrease the threshold level of the quad-cell amplifier.

The test results when scaled for 0.5 deg, 0.08 Hz sinusoidal motions are:

1. 0.5 deg, 0.08 Hz rough motion of the tracker base was tracked out to  $35 \mu\text{rad}$  precision rms, with  $35 \mu\text{rad}$  lag and occasional  $140 \mu\text{rad}$  excursions.
2. Splendid performance to a precision of  $20 \mu\text{rad}$  or better. System oscillation resulted when  $10 \mu\text{rad}$  precision was attempted.
3. Static control to 1 bit ( $50 \mu\text{rad}$ ) was demonstrated for both azimuth and elevation. Both joy-stick and track-ball control were demonstrated.
4. Turbulence considerations will require a larger aperture quad-cell optical system.
5. The AC motor and magnetic amplifier drive systems should be replaced in the interest of precision, better transient response, and reliability.

## SERVO SYSTEM

During recent tests we attempted to produce a servo system that would allow quad-cell tracking of a target from a non-stationary platform. Overall, the attempt was largely successful.

Besides doing tests to determine performance we also generated Bode plots of various servo loops. Figures 10 and 11 show the mag-amp to tach loop response for azimuth (AZ) and elevation (EL). One can see the basic 20 db/dec roll-off due to inertia. In addition, there appears to be additional roll-off due to the mag-amps followed shortly by a mechanical resonance zero and pole. These resonances have considerably more structure in AZ than indicated but measurements are difficult to make. The figures can be summarized:

<u>Mag-Amp to Tach Loop</u>	<u>AZ</u>	<u>EL</u>
Mag-amp approximate corner frequency	6.5 Hz	6 Hz
Resonance zero frequency	10-11 Hz	12 Hz
Resonance pole frequency	18 Hz	14-15 Hz

A proportioning type closed tach loop was installed and the closed loop Bode plots (Figs. 12 and 13) were measured. In order to compensate somewhat for the mag-amp roll-off some lag was put into the tach feedback to produce some lead in the closed loop. These results are summarized as follows:

<u>Closed Tach Loop</u>	<u>AZ</u>	<u>EL</u>
-3 db pt	5.5Hz	2Hz
Gain margin	10 db	20 db
Phase margin	90 deg	90 deg

Higher crossover frequencies might be possible when more time permits. This is especially true for elevation where a 15KHz mag-amp to tach cable resonance caused problems.

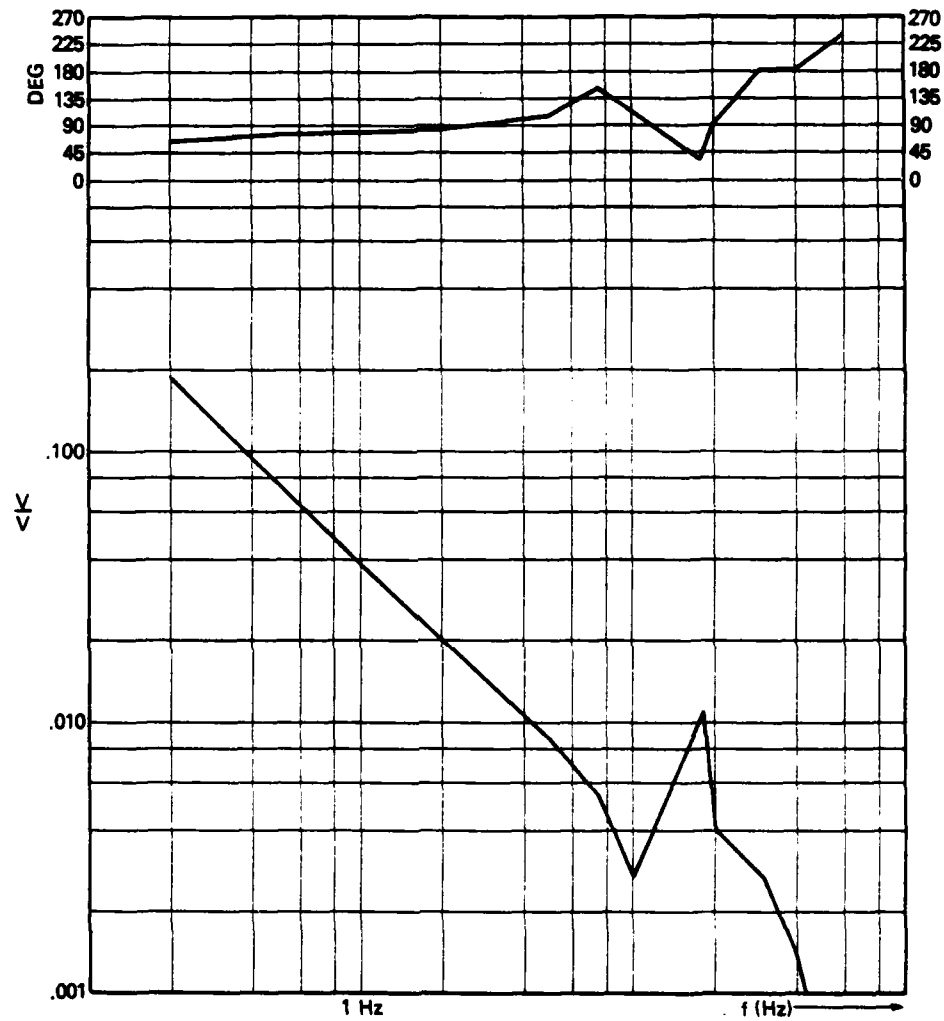


Fig. 10 — Bode plot of tach output to mag amp input for azimuth

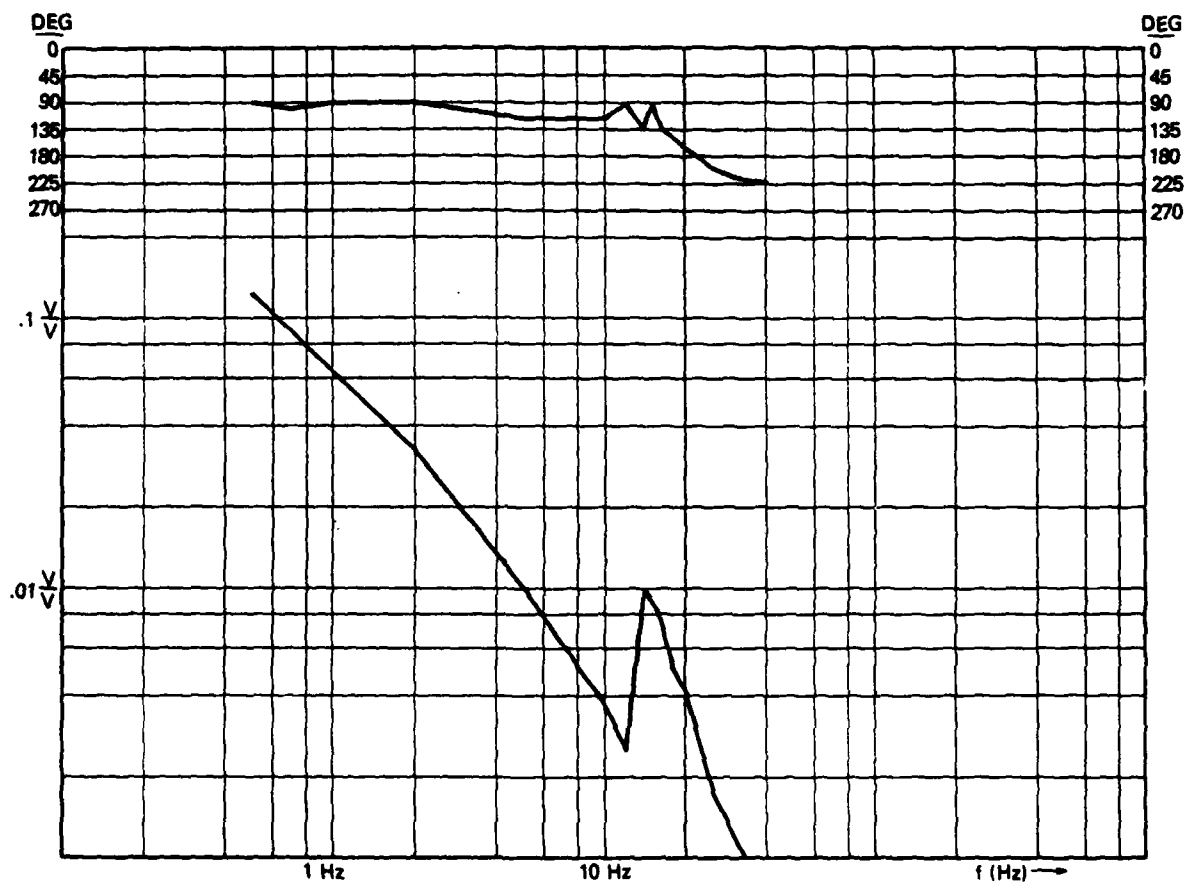


Fig. 11 — Bode plot of tach output to mag amp input for elevation

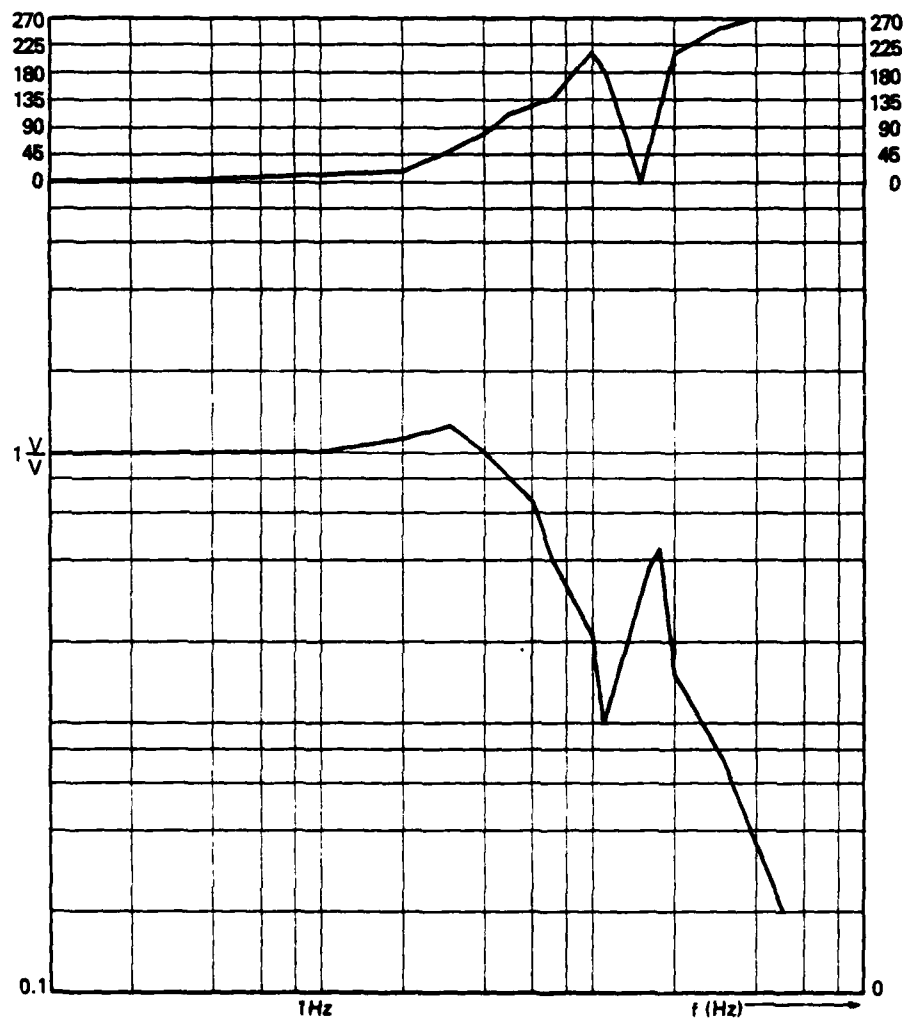


Fig. 12 — Bode plot of closed tach loop response for azimuth

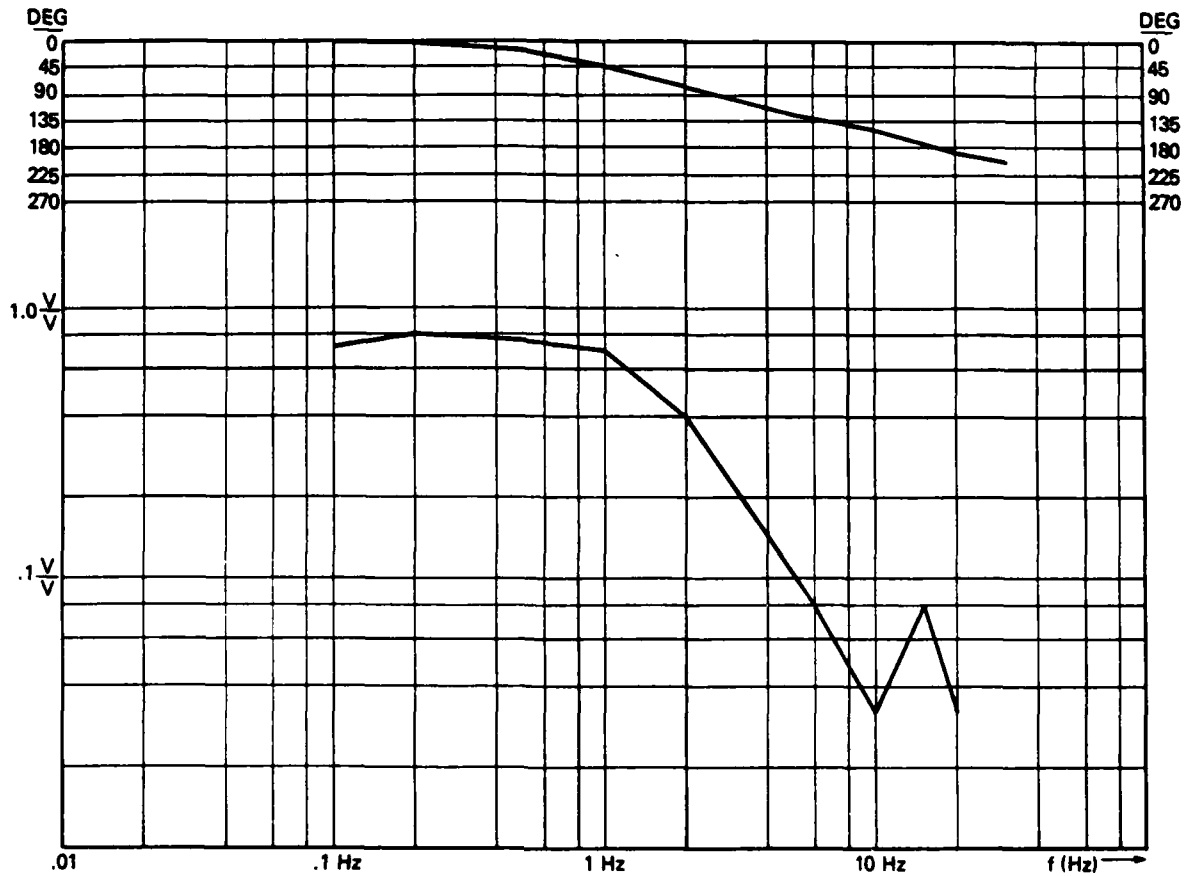


Fig. 13 — Bode plot of closed tach loop response for elevation

Integrating positioning loops were installed and these open-loop responses for azimuth and elevation were measured as in Figs. 14 and 15. One sees the basic Type II response shifting over to Type I before crossing the unity gain axis. These results are summarized as follows: (Note EL is pessimistic. Small signal excursions produce more margins but are hard to measure)

<u>Open Loop</u>	<u>AZ</u>	<u>EL</u>
Acceleration error constant	30 (rad/sec) <sup>-2</sup>	25 (rad/sec) <sup>-2</sup>
Gain at 0.08 Hz (ship roll frequency)	115 (rad/sec) <sup>-2</sup>	100 (rad/sec) <sup>-2</sup>
Cross-over frequency	2 Hz	1.4 Hz
Phase margin	80 deg	> 15 deg
Gain margin	7 db	> 3db



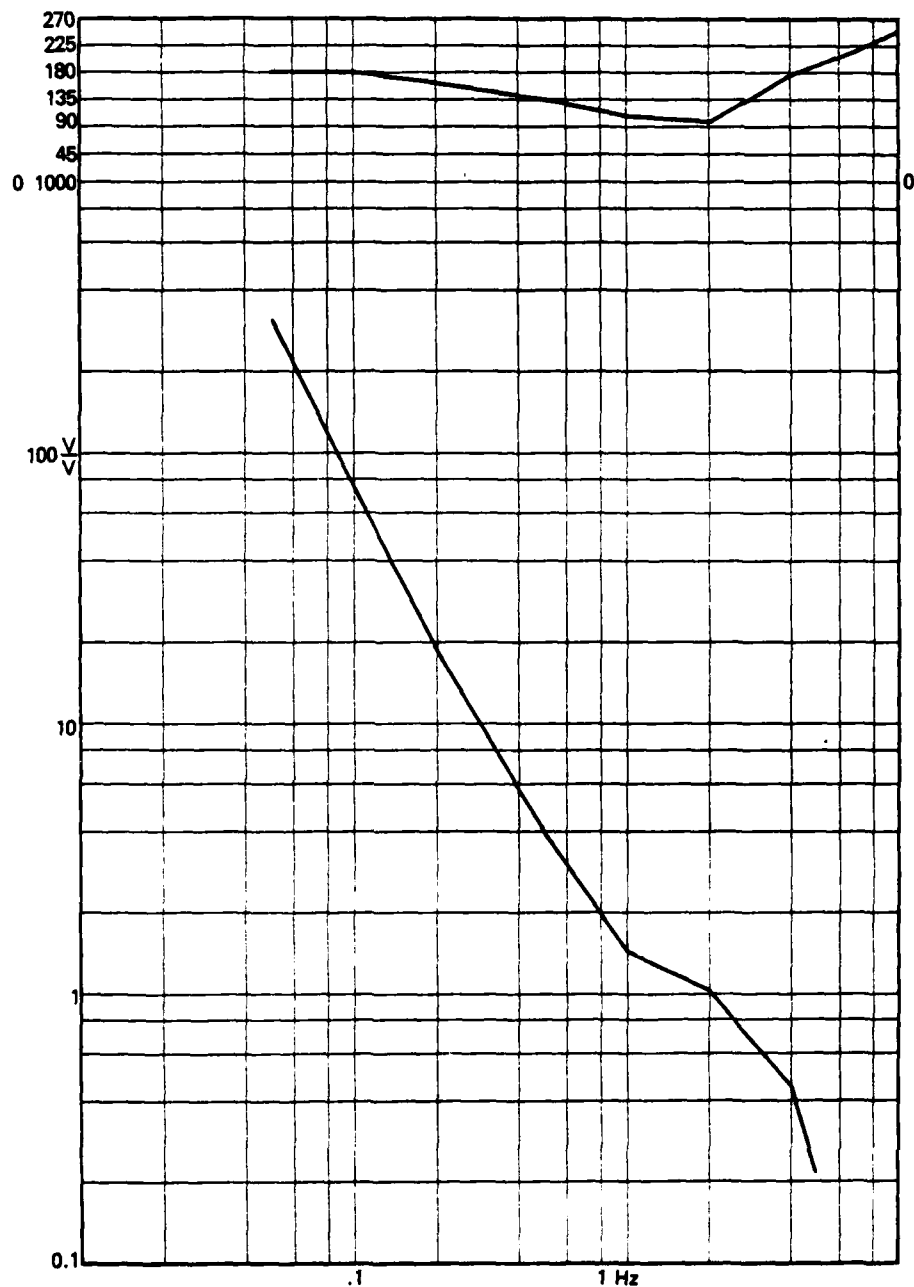


Fig. 14 — Bode plot of open position loop for azimuth

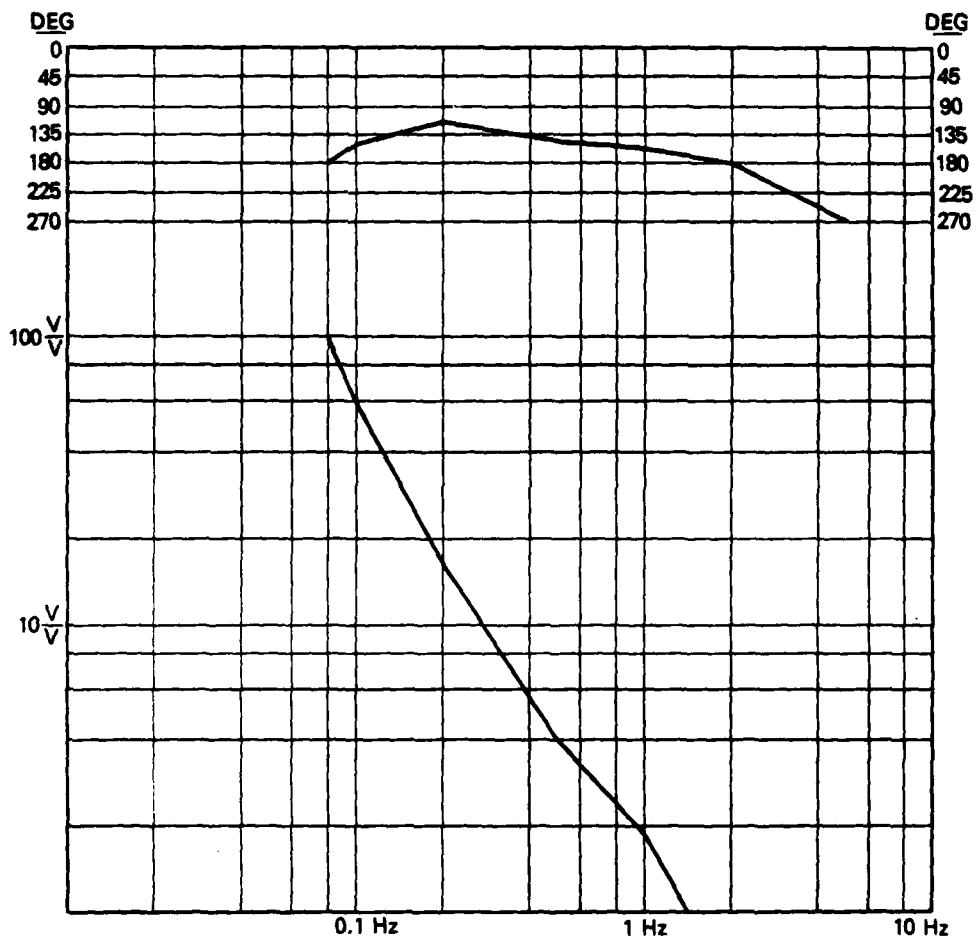


Fig. 15 — Bode plot of open position loop for elevation

Because of time constraints, we did not measure the closed loop position response with the quad cell as a feedback element. This could be done in the future.

Yawing in AZ was simulated by injecting a signal inside the loop, which when opened, produced a deflection of 26.6 mrad at 0.08 Hz. Closing the loop reduced the error to 75  $\mu$ rad as read by 50  $\mu$ rad/bit shaft encoders.

Lastly, a quad-cell tracker was used as a position sensor for elevation. This should change the gain magnitude only, since its response is flat to 160 Hz. Results for this experiment are presented in the Tracker Test Results section.

In the future Type I loops will be used to handle large excursions with automatic switching to Type II loops. Since Type I loops are much easier to build, and are not used to obtain small errors, the limited time necessitated concentrating on the Type II loops discussed above.

## DC TORQUE MOTOR ADVANTAGES

Substituting DC torque motors and linear amplifiers for the AC motors and magnetic-amplifiers (mag-amps) currently used would have several beneficial effects if done properly.

From a servo-design standpoint, the most important reason for replacing the present motors is that the mag-amp roll-off would be eliminated. This would allow an increase in the tachometer loop -3 db point, (a factor of two should be possible). This allows the option of either a higher gain on type II loops (a factor of four can be gained since the roll-off there is proportional to  $1/f^2$ ), or with the same low-frequency gain one could increase the high-frequency gain and produce much better damping, especially in elevation. This last option will become more important when acquisition, as well as tracking, is considered.

The mag-amps and DC motors exhibit two other annoying characteristics. First, linearity including a dead zone, is 10-20% at best. Second, they have a tendency to wind-up, that is, once started the motors will drive at near full power with no input to the mag-amps. This puts a much greater burden on the tach-loop, especially for large excursions and this explains the apparent poor stability in the position loop. Both of these deleterious effects would be completely eliminated with the substitution of DC hardware.

An additional problem is pick-up. The large amount of 400 Hz power produced by the generator to power the AC motors, and the several-volt inductive spikes induced on even the ground leads, may become a problem when the remaining instruments are installed in the tracker trailer. Although the DC motors do produce brush-noise EMI, this noise can be filtered at the source.

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If this modification is undertaken, little extra effort would be involved in using better integral tachometers, or using the shaft encoders themselves. The present tachs, although adequate, could become a problem due to the large amount of common-mode pick-up, and their large warm-up drift. Operationally, if both these modifications are undertaken, the 400 Hz generator could be eliminated. A further advantage would be a reduction of the spare-parts problem. "Even when they can be obtained", as Stuart Field of China Lake has remarked, "no two mag-amps are alike." Since 60 Hz power could be used to generate the DC power, no less-obtainable 400 Hz equipment would be required.

In summary, even though the present AC motors could be used, performance would be enhanced and long-term cost effectiveness would be considerably improved if the conversion to DC equipment were made.

#### DF LASER CONVERSION TO $\text{NF}_3$

Appendix I, kindly furnished by TRW, describes the modifications done on the DF laser to convert it to use  $\text{NF}_3$  as the fluorine source. *Figure 16 shows the modified laser head.* The obvious external evidence of the modification is the pressure transducer on the side and the spark plug and the small precombustor chamber directly above it. A test of the modified laser on 12 November 1981, was successful. The laser power output was over 5 watts multi-line and 0.5 watts single-line on both  $P_1(8)$  and  $P_2(8)$ .

#### DF LASER VACUUM PUMP OVERHAUL

The fuel flow system of the NRL chemical laser is based on the smooth and dependable operation of the vacuum pump. The main components consist of a 200 cfm Stokes reciprocating pump, and a Roots turbine. The turbine effectively boosts the system pumping capacity to 1600 cfm. The laser combustion chamber is operated at about 1-2 torr vacuum. The gas exhaust passes through a soda-lime trap before entering the pump. The purpose of the trap is to neutralize the hydrofluoric acid exhaust before it encounters the pump. We normally change the pump oil after each day of use for preventive maintenance.

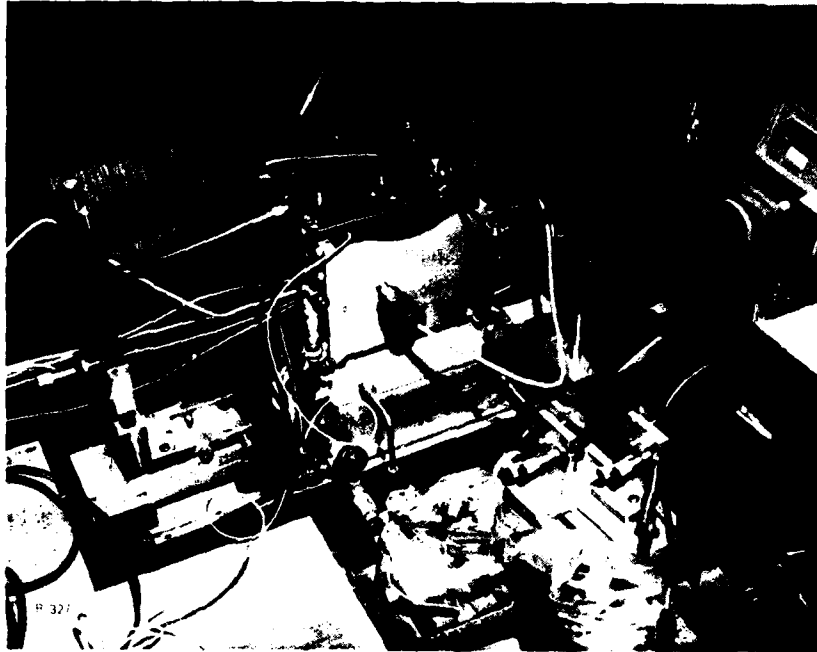


Fig. 16 — DF laser with  $\text{NF}_3$  modifications

Even with these precautions, the pump eventually has to be overhauled due to the corrosive action of the residual HF (DF) gas. This operation was completed in October by Mr. C. Gott of our group. The following work was done on the pumping system:

1. Install new valves, springs, and seats.
2. Install a new drive shaft, with new bearings and seals.
3. Install a new needle valve in the oil regulator.
4. Steam clean the inside pump surface.

The new components were tested first with  $\text{F}_2$  fuel, then with  $\text{NF}_3$  fuel. No problems were encountered. Figure 17 is a photograph of the pumping system as installed in the new pump/supply trailer.

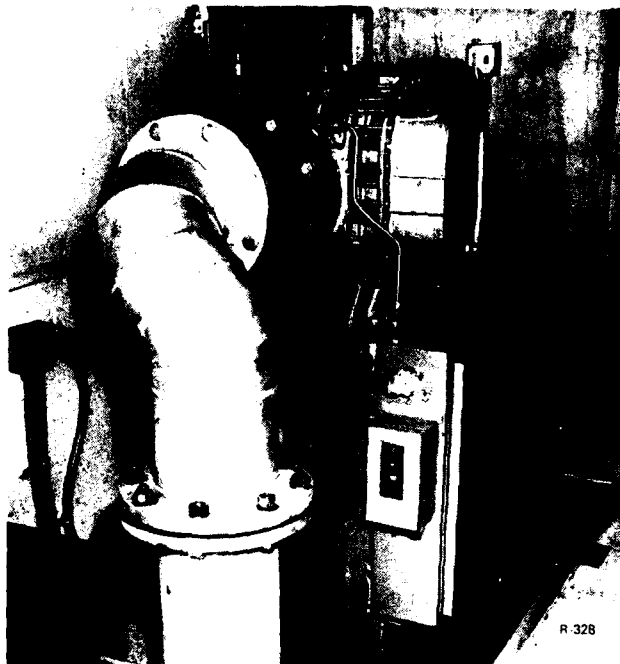


Fig. 17 — DF laser vacuum pump in new pump/supply trailer

#### **FTS HARDWARE/SOFTWARE MODIFICATIONS**

During Oct-Dec, 1981, MIDAC Corporation performed an extensive overhaul and upgrade of the NRL MIDAC-1000 Fourier Transform Spectrometer. Many advances in both hardware and software have occurred since the construction of this device in 1976. Also, the NRL device had suffered some deterioration due to its use in field experiments at diverse sites. The device is currently being set up in the NRL spectroscopy laboratory. The improvements include:

##### **Hardware**

1. New fixed mirror plate, wedges, and gear tower.
2. All new optics.
3. Rerouted air bearing air supply.

4. Completely new electronics for both the interferometer controls and the new A/D converter (100 kHz).
5. New HeNe laser and mirror mount.
6. New interferometer drive motor.

#### Software

1. Entirely new Fortran package and transform software.
2. Original 32 bit precision retained throughout.
3. Included a more sophisticated co-add algorithm.
4. Device operation is now menu-driven.

#### COMMUNICATIONS SYSTEM

In an operational environment as complex as the one that will exist during the proposed measurement, communication plays an important role. Not only are the two ends of the experiment on separate ships, but there will be several activities within the tracker trailer itself. These activities, if not occurring simultaneously, at least need to be coordinated with a minimum effort in a short period of time.

We have designed and constructed a communications system, as shown in Fig. 18, that includes the following: voice-controlled headsets, a mike-switch-controlled marine-band radio, TV cameras, TV monitors, and a video tape recorder. All voice communications are level-controlled and recorded on the voice track of the video tape recorder. One TV camera is mounted on the tracker mount and is bore-sighted to observe whatever the mount points at. A second camera views an instrument panel inside the trailer which has displays of temperature, dewpoint, wind vector,  $C_T$  level, and the level of the laser signal during the transmittance measurement.

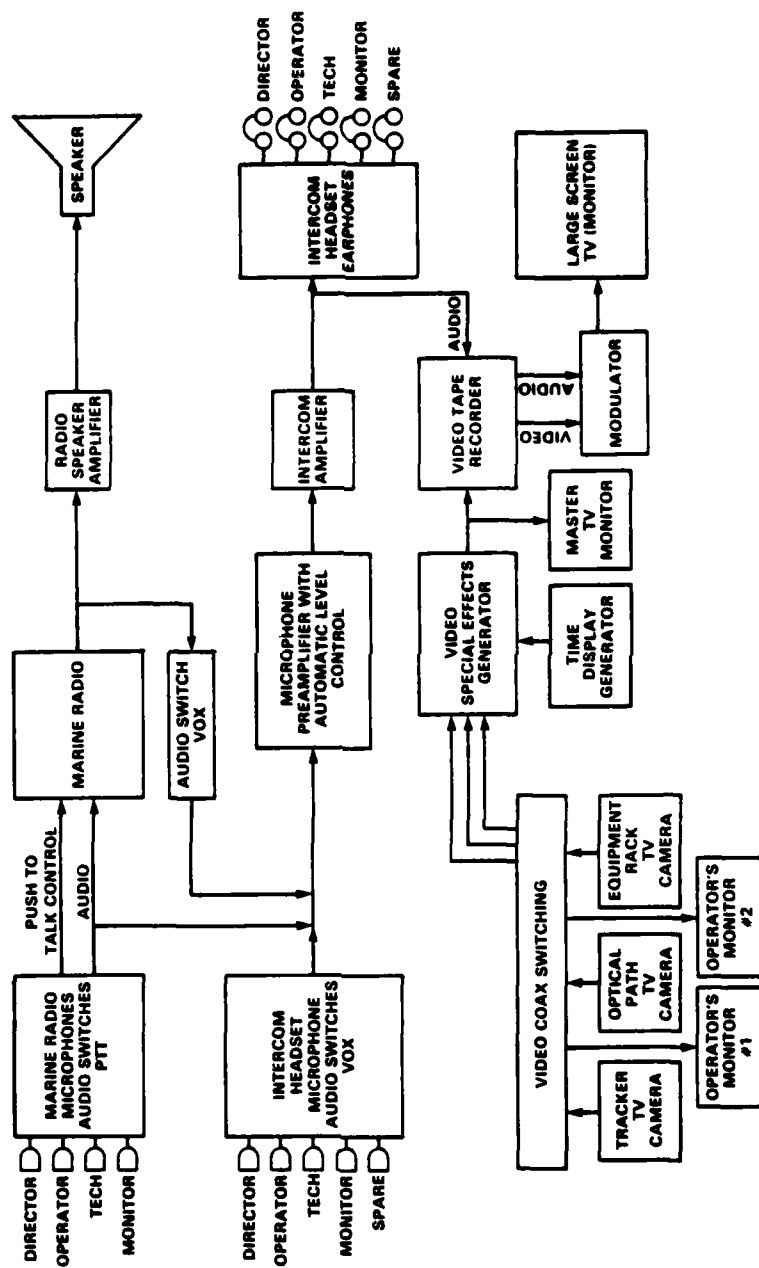


Fig. 18 - Block diagram of communications system



To assure a proper documentation reference, a video time-code generator output is mixed with the instrument-panel camera's signal to form a time and date display on the monitor. A special-effects generator allows a side-by-side display of that mixed signal with that of the tracker-mounted camera. Thus, during operation, all this information is viewable on each monitor in the trailer. The video tape recorder saves that information for later viewing during the data analysis.

Figure 19 shows a view of the layout of the trailer pointing out the locations of the major elements of the communications system. The rack in Fig. 20 shows the mounting of some of the communications equipment in the trailer.

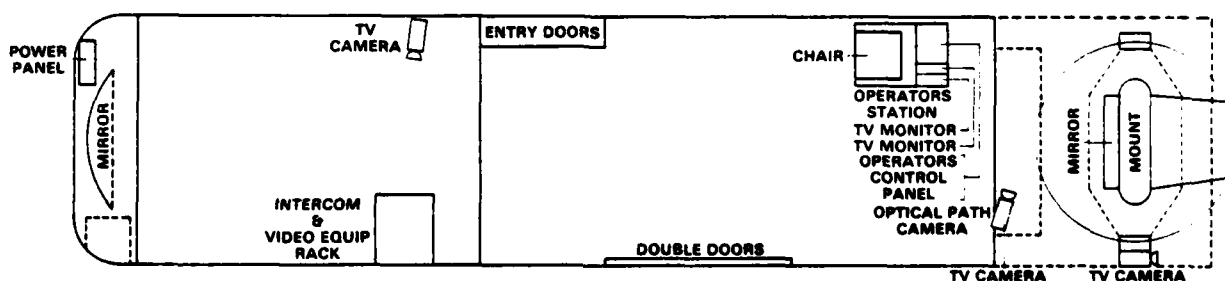


Fig. 19 - Tracker-trailer layout

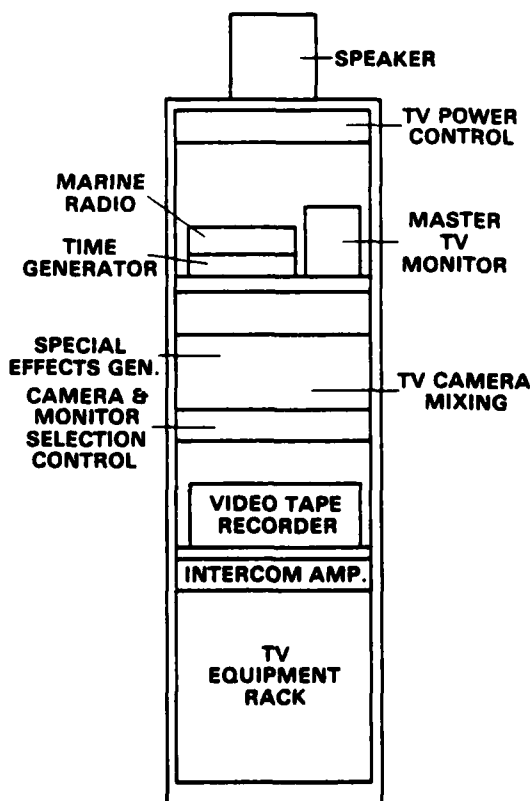


Fig. 20 - Rack with communications equipment

## USS LEXINGTON VISIT

On 27 October 1981 four of us from NRL and LCDR S. Grigsby from NAVSEA PMS-405 visited the USS LEXINGTON to meet the current ship personnel and brief them on the proposed ship-to-ship measurements. The visit also allowed us to examine the measurement locations for unexpected problems that may have arisen since our Near-Ship measurement on LEXINGTON in 1979. (G. L. Trusty, T. H. Cosden, S. Craig, and P. C. Ashdown, "Measurements of Optical Propagation Parameters Aboard the Aircraft Carrier USS LEXINGTON," NRL Memorandum Report 4716). The only problem encountered was an installation of an air-conditioning condenser in the forward starboard gun tub that will modify our approach to shipboard optical turbulence measurements.

We consider the visit a success in that lines of communication are again open between NRL, NAVSEA PMS-405 and LEXINGTON and that we encountered only friendly willingness to aid in our endeavor. The trip report in Appendix II describes the results of the visit.

## ESCORT SHIP

The escort ship is specified by the requirements of the experiment. Specifically, these requirements are outlined in Appendix III, which follows the format directed by *OPNAVINST 3960.10A* and was submitted to PMS-405 on 9 December 1981. Also in Appendix III are two other documents, LEXINGTON SHIP-TO-SHIP TRANSMISSION REQUIREMENTS FOR ESCORT SHIP, and SUMMARY OF NRL-USS LEXINGTON BRIEFING, which were included with the RDT&E SUPPORT REQUEST. Support requests for fourth quarter FY82 or first quarter FY83 should be submitted before 1 April 1982, or 1 July 1982, respectively. Additional points of contact are as follows:

1. 2nd Fleet Scheduling NORVA      AV 690-7201
2. LCDR J. Pendelton, OPCAV4      AV 690-5063/4.

## **SAFETY**

Although there exist many safety issues in conjunction with an operation of this size and complexity, the over-riding factor here is the problem of the  $\text{NF}_3$  combustion-driven DF laser. A device of this type has never before been operated aboard a ship. And, in light of the fact that the Navy is proposing future shipboard installations of much larger devices, it is very important that every conceivable accident possibility be addressed. PMS-405 has taken the lead in this area. The result of the first phase of their safety study is found in the SAI report "Shipboard/Dockside Safety-Related Data Collection," 23 October 1981. A preliminary Hazard Assessment Study Report is due in February 1982, also from SAI, and NRL will provide a laser-operation procedures report in March.

We have been in contact with Mr. E. Eisenberger of PMS 405 concerning the safety studies. We have arranged a visit and an equipment tour for him and Mr. J. Chapman of SAI on 2 February 1982.

## **PLANS**

The ship-to-ship experiment was originally scheduled for September 1982. We now believe, however, that it is unlikely that the experiment will occur before December 1982. First, there was a delay in getting the contract out to Massachusetts Manufacturing. And, for various reasons, we did not receive the optics until November. Also, the safety study will delay the final installation of the DF laser. As a result, even if we drop the preliminary shipboard checkout of the tracker, which we now propose to do, we do not recommend that we go aboard LEXINGTON before the end of the fiscal year. Although the tracker assembly will be complete by that time, we would not be able to do the comprehensive land-based shake-down testing that would assure success in the actual shipboard test. And, since LEXINGTON goes into the yards for two months starting in October, our first opportunity to go aboard will be in December.

One of the prime motives for initially proposing a preliminary shipboard tracker checkout was to determine the effect of any ship vibrations on the tracker. Knowing the screw shaft speeds we have estimate expected vibration frequencies from that source and do not expect them to be a problem. The

unexpected and unknown, of course, are what causes difficulties. For example, we know that the impulse-like firing of the steam catapult (located just above the tracker operating position) undoubtedly excites many structural resonances aboard. We do not know what frequencies they are or of what amplitude. It is important that we investigate this prior to the ship-to-ship measurement so that we can "design out" unexpected resonance interferences. We have, in the course of testing the tractor servo system, plotted open-loop frequency responses of both the azimuth and elevation. A 12 v square wave drove the systems and we recorded the tachometer responses. Resonances do exist, as shown in Fig. 21, so we must determine if an unknown shipboard source will excite them.

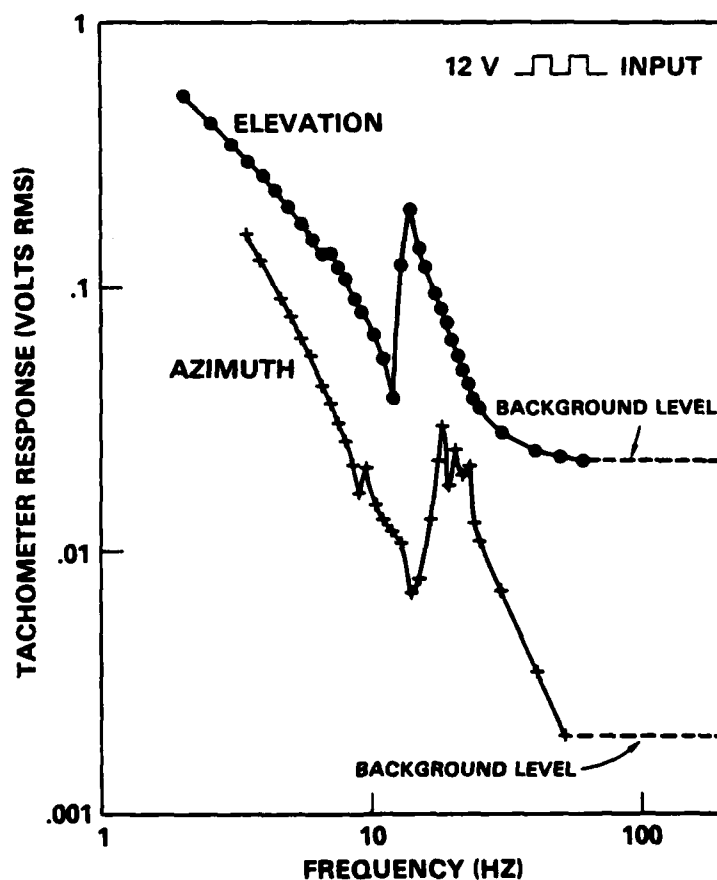


Fig. 21 — Tracker mount resonances

Since it is possible to obtain vibration information in other ways than doing an onboard tracker test, and, since the information should be available prior to final servo design, we will first go aboard LEXINGTON for several operational days with accelerometers, recorders, and a spectrum analyzer to determine the extent of the induced resonances at the tracker operation location. That experiment is planned for late March 1982.

Another change in the schedule which has not yet occurred, but is strongly recommended, involves the servo motors on the tracker. Currently they are 400-Hz ac motors driven by magnetic amplifiers. Both the motors and the mag-amps are definitely sources of problems in the servo system due to nonlinearities such as wind-up, dead spots, and low-frequency roll-off. The *DC Torque Motors Advantages* section of this report explains these problems in more detail. We recommend that we replace the motors and mag-amps with modern dc versions, noting that other organizations working with modified Nike-Hercules mounts are doing the same. The cost of the conversion should be well offset by the simplification and reliability of the new design.

#### ACKNOWLEDGMENTS

Many people besides the authors have contributed to the successful status of the project. John Cox of the CBD shop constructed much of the optical mounting equipment, and served long hours during the tracker test together with Charles Gott. Frank Tidball and Patrick Delaney of Sachs/Freeman designed and constructed much of the tracker wiring and electronics, together with the communication system. Henry Bobitch of TRW Inc., performed the DF laser conversion to  $\text{NF}_3$  operation. Jerry Auth of MIDAC Corporation performed the FTS overhaul. We appreciate the fine photographic work of Mr. C. V. Acton. And we appreciate the continuing enthusiasm and encouragement from LCDR Stan Grigsby of NAVSEA/PMS-405, and Dr. J. Richter of NAVSEA/EOMET.

**Appendix I**

**TRW DOCUMENTS FOR CONVERTED DF LASER**

### DESCRIPTION, MODIFICATION FOR $\text{NF}_3$ OPERATION

The NRL HF/DF laser oscillator has been modified to operate on  $\text{NF}_3$  as an oxidizer. Since  $\text{HF}_3$  and  $\text{H}_2$  are not hypergolic, a means of ignition must be provided. In addition, a dual set point vacuum controller has been incorporated into the gas control system to provide for automatic shut off of reactive fluids in case of combustor flame out, or laser malfunction that produces overpressure, such as failure of the vacuum pumping system. A penetration has been made in the combustor. This serves as a duct for the fluorine atoms and hot molecules formed in the ignitor. The attached ignitor has a separate feed system to supply  $\text{NF}_3$ ,  $\text{H}_2$ , and a purge gas. A modified spark plug is used to decompose the  $\text{NF}_3$ . An electronic package furnishes electrical energy to the plug. The control panel now includes a vacuum controller over-ride switch to enable all fire valves while the laser is not operating. Gas flow rates are set while in the over-ride mode, and an additional solenoid valve to operate pneumatic valves used in the ignition system. A "Start" button is used to actuate the solenoid valve and to turn on the electronic source for the spark plug. The gas control panel now contains a fixed sonic orifice for metering respectively, the  $\text{NF}_3$ , and  $\text{H}_2$  and purge gas to the ignitor. Pneumatic valves are used to start and stop the flow. A new set of run conditions will have to be found empirically. The substitution of  $\text{NF}_3$  for  $\text{F}_2$  changes the molecular species in the combustor and in the laser cavity. It is expected that combustor pressure will be higher, requiring higher gas fuel rates. All safety and maintenance procedures are unchanged.

### MODIFICATION TO START-UP PROCEDURE

In order to set flow rates with the laser in its present configuration, the vacuum controller over-ride must be activated. After desired flows are set, pressure limits are set on the vacuum controller such that the flows will be shut down in case of flame out or of too high combustor pressure. The over-ride is now disabled. When the "Start" button is pushed, the spark plug is energized,  $\text{NF}_3$  and  $\text{H}_2$  are furnished to the ignitor, and all fire valves are enabled. The button should be held down until the combustor pressure is in the run window. At this point, all fire valves are enabled through the vacuum controller.





SK

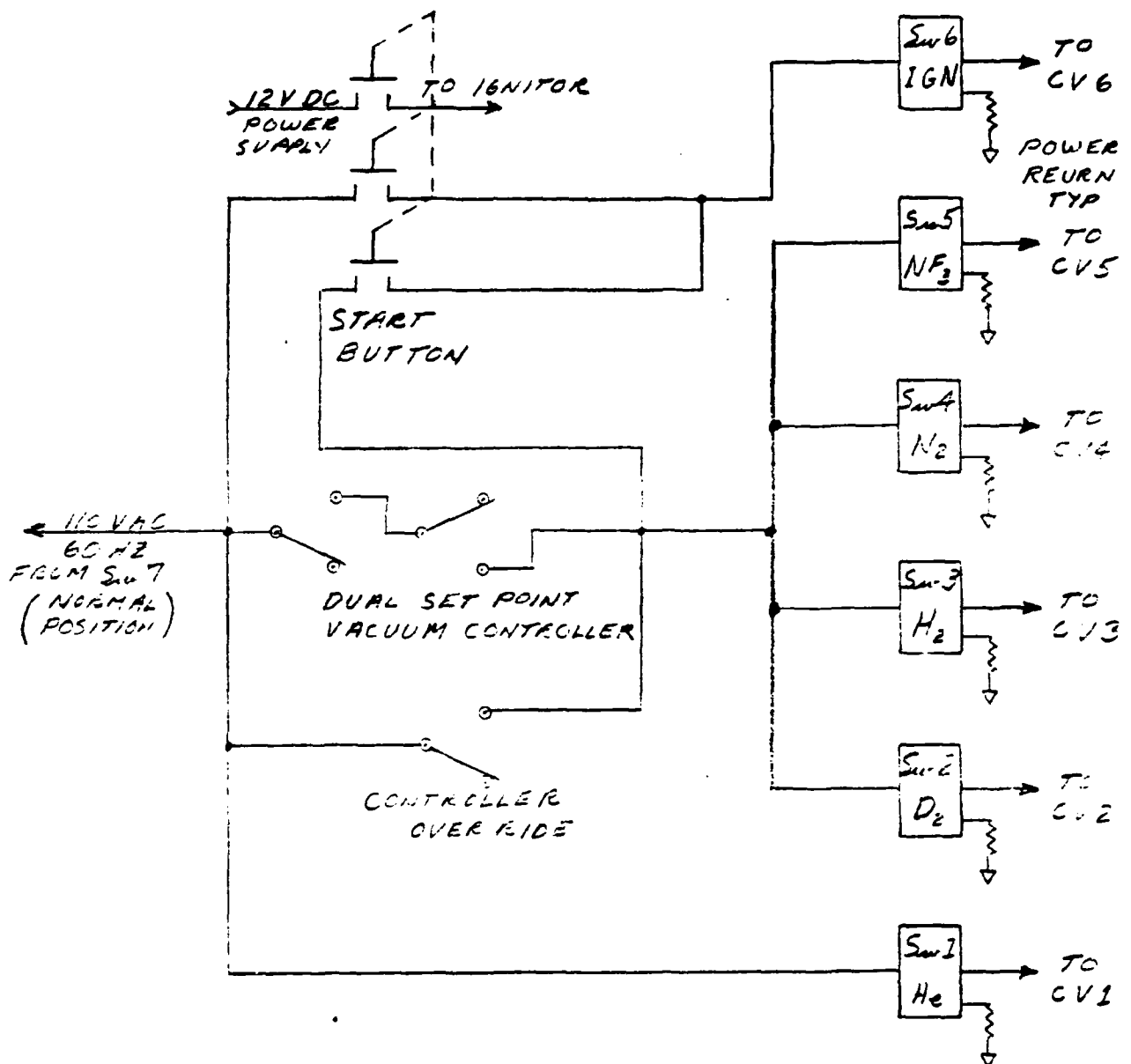
## REVISIONS

LTR

DESCRIPTION

DATE

APPROVED



## ENGINEERING SKETCH

**TRW**

SYSTEMS GROUP

ONE SPACE PARK • REDONDO BEACH, CALIFORNIA

ORIGINATOR

DATE

Pc 10/21

29 Sept 61

MODIFICATION, CONTROL PANEL  
FOR IGNITOR & CONTROLLER

SIZE

CODE IDENT NO.

A

11982

SK

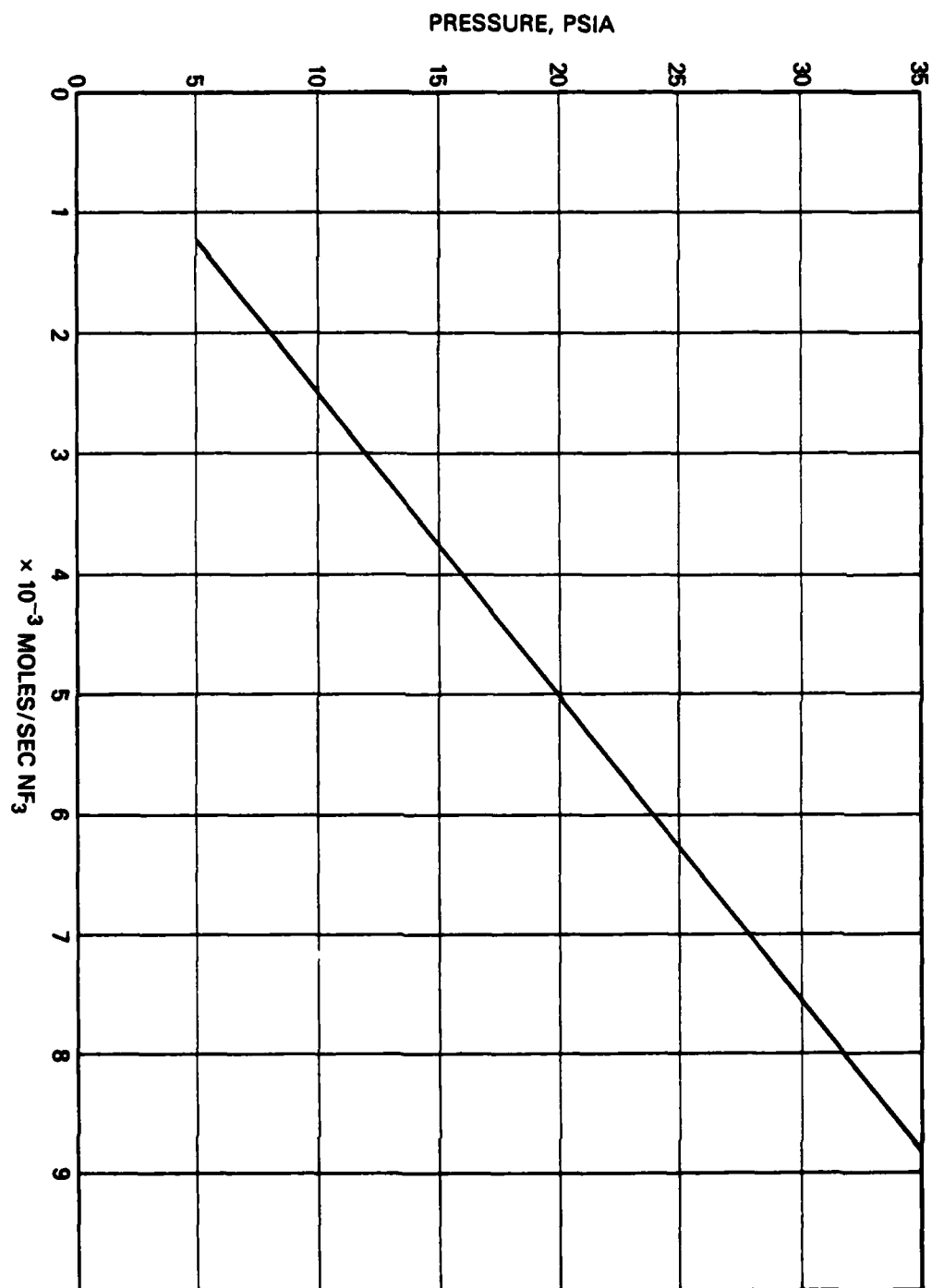
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MJO

SCALE

SHEET 1 OF





**Appendix II**  
**TRIP REPORT FOR USS LEXINGTON VISIT**

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## CONSULTATIVE SERVICES RECORD

NDW-NRL 5211/1103 (Rev. 4-78)

CLASSIFICATION:

UNCLASSIFIED

INSTRUCTIONS: This form is to be prepared in triplicate and signed by the conferee after each conference between Laboratory personnel and outside persons. (When contracts are discussed, a separate copy shall be prepared and forwarded to Code 2400 and the route sheet so noted.) Retain one copy and route two copies to Division Head, cognizant Associate Director of Research and Codes 1240, 1010, 1200, 1300 (if financial matters are discussed), 2004 and to 2121.1 for file.

1. DATE PREPARED 4 November 1981	2. CLASSIFICATION AUTHORITY UNCLASSIFIED	3. IDENTIFICATION SYMBOL AND/OR NRL SERIAL NO. 6530-604:GLT:b1e
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## 4. CONFERENCE DATA

(a) DATE OF CONFERENCE 10-27-81	(b) PLACE USS LEXINGTON
(c) NAME(S) OF LABORATORY PERSONNEL G. L. Trusty	(d) DIVISION AND CODE NUMBER 6532
D. H. Leslie	6532
T. H. Cosden	6532
LTJG E. Gaynor	6530
(e) NAME(S) OF OUTSIDE PERSONS LCDR S. Grigsby	(f) ACTIVITY & ADDRESS REPRESENTED PMS 405, NAVSEA
CMDR "Raider" Roark, Air Officer; CMDR John Kelly, Air Ops Officer; LT Burgess, Met Officer; and Chief Koessler, Met Assistant	USS LEXINGTON, Pensacola
(g) PURPOSE OF CONFERENCE Discuss proposed Ship-to-ship measurement.	
(h) TIME CONSUMED IN CONFERENCE 3 hours	(i) CONTRACT NO./RFP OR IFB (if applicable)
(j) HIGHEST CLASSIFICATION OF MATERIAL DISCUSSED IN CONFERENCE UNCLASSIFIED	(k) NRL PROBLEM NUMBER (if applicable) 65F201-0.2

5. BRIEF OF RESULTS

See attached sheet.

6. SIGNATURE

G. L. TRUSTY, Applied Optics Branch

CLASSIFICATION:

UNCLASSIFIED

I introduced the players on our side and gave a brief introduction as to why we were there. D. Leslie gave a 20-minute vugraph presentation showing some history and details of our project. Discussions followed. CMDR Kelly says there are two types of operations they perform. One is where they handle only training flight qualifications out of Corpus Christi. (That is what they were doing on our July 1979 cruise). Aircraft there are T2's and TA4's in daylight only. During the other type they trap and launch planes from a group referred to as RAG flyers (Replacement Air Group) who have been out and are returning to squadron level. This operation occurs off Pensacola. Aircraft included are A6's and A7's as well. Night flights occur for this operation.

We discussed the escort ship, noting that the reserve destroyer Owens is still docked in Pensacola. They say she is to be decommissioned in December 1981. CMDR Roark said that there are two reserve destroyers in Tampa-St. Pete and some appropriate craft may be docked in Pascaboola or Panama City. CMDR Roark suggested that we add to our Escort Ship Requirements that the maximum surface speed of LEXINGTON is 27 knots.

LCDR Grigsby asked about bringing in a small plane to make a few passes along the propagation path for a half hour duration. Roarke and Kelly thought it could be arranged without much difficulty.

We visited the forward hanger bay starboard doorway where our trailers are to sit. The roller curtains which were rumored to be welded shut were actually in the process of being replaced. (The fire aboard NIMITZ had an effect on this new decision). Roark could see no problem with the placement of the trailers. The roller curtain controls will have to be disabled while we are aboard to prevent accidental closure on the tracker which extends over the threshold.

Roark also requested that we add tie-down rings to both trailers—three on each side and one on each end.

We briefly discussed the schedule. They will be in port two or three weeks before the last cruise of the year before going into the yards for about two months. This last cruise is in September 1982 and will last 12-14 days, encompassing both a training operation at Corpus Christi and a RAG operation at Pensacola. Personnel transportation on or off will be possible between the two operations. Upon leaving the yards in November or December, LEXINGTON will steam to Key West, where winter flight operations are to occur. This is apparently a new procedure.

After the meeting LCDR Burgess took us to the forward starboard gun tub, where we planned to repeat the July 1979  $C_T$  measurement, with a Schlieren measurement added on this cruise. A very large air conditioning condensor unit has been placed in the tub not 12 feet from the proposed  $C_T$  measurement location. That proposal must now be reconsidered. Burgess also took us to the aft starboard gun tub. It is as it was in July 1979.

Action items. We are to contract AIRLANT to make them aware of the proposed project. They and SURFLANT should help us identify a second ship.

**Appendix III**  
**ESCORT SHIP REQUEST**

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## RDT&E SUPPORT REQUEST

### I. CNO T&E ID#

PROJECT NAME - High Energy Laser CNO Project # 340

PROGRAM ELEMENT - 62735N

PROJECT 3 - SF35-388

### II. PURPOSE

#### 1. BRIEF PROGRAM PURPOSE

- a. To validate models predicting the propagation of DF laser radiation through the marine atmosphere by measuring the infrared transmittance between two ships at sea.
- b. To evaluate the utility of using current meteorological instrumentation for predicting electro-optic performance in the marine environment.
- c. To determine whether shipboard transmittance measurements correlate with existing land-based measurements.
- d. To demonstrate the feasibility of operating a large aperture, precision optical tracker aboard a Navy ship.
- e. To demonstrate the feasibility of operating an NF<sub>3</sub> combustion-driven DF laser aboard a Navy ship.

#### 2. PLANNED TEST

- a. A re-modeled Nike Hercules Tracking Radar mount will send a 32 in. diam. infrared laser beam across fixed distances (0-5km) from the hangar deck on the starboard beam of the USS

LEXINGTON to a 60 in. diam. receiving "light bucket" located on the main deck of the escort ship. Instruments on the escort ship will measure dew point, aerosol particle size distribution, wind speed and direction, and temperature. Four men will operate the laser and tracker aboard the LEXINGTON. Three men will operate the 60 in. modified search light ("light bucket") along with the weather and aerosol detecting devices aboard the escort ship.

b. SPECIAL CONDITIONS

- A. The roll of the sending ship, which carries the laser tracker is specified at only a few degrees. Therefore calm seas and a stable platform are required.
- B. Aircraft landings and launchings are needed to create an aerosol distribution similar to that of an operational environment aboard a carrier.

c. AVAILABILITY OF TEST PLAN

The test plan is available.

III. REQUIREMENTS

1. Two ships are required:

- The availability of the USS LEXINGTON and her ability and willingness to support this experiment have been unofficially determined. Encl. (2)
- The escort ship must fill the requirements outlined in Enclosure (1)
- An acceptable alternative would be two ships similar to the two above in space and operational ability.

a. DAYS

The escort ship will be required for no more than 21 days.

b. HOURS

Escort ship needed up to 12 hrs during daylight hrs.  
No support needed during night-time hours.

c. LOCATION

The two ships must operate in relatively calm seas similar to those in the Gulf of Mexico, according to the requirements of the tracking system.

d. LEVEL OF SUPPORT

Concurrent

e. DATES

Late Summer - Fall 1982 preferred.  
Begin no sooner than 1 Aug. 82  
Complete not later than 1 Dec. 82

IV. EQUIPMENT

1. EQUIPMENT TO BE INSTALLED

a. DESCRIPTION

- A. To be installed on LEXINGTON: Two trailers and one tractor.
- B. To be installed on escort ship: See Enclosure (1)

b. INSTALLATION

- A. LEXINGTON: Power - 440V (3-phase), 60 cycle
- Starting Load - 45kw
- Average Load - 20kw

b. INSTALLATION - (Con't)

A) LEXINGTON: Space - 800ft<sup>2</sup> starboard beam hangar deck.

Trailer #1 - 39ft.

Trailer #2 - 30ft.

Security - None

Weight - Tractor #1 - 22,000lbs.

Tractor #2 - 25,000lbs.

Tractor - 15,000lbs.

Access - Ready, constant.

B) Escort Ship: Power -110V (single phase), 60 cycle

- At aerosol van - 10 kw

- At 60 in. searchlight - 5 kw

Space - As indicated in Enclosure (1)

Security - None

Weight - Aerosol van - 13,000 lbs.

Searchlight - 2500 lbs.

c. AUTHORIZATION

2. INSTALLATION AND REMOVAL PERSONNEL

a. A crane and operator and a working party will be

needed for installation of equipment on both ships.

NRL personnel will complete installation once the equipment is aboard the ships.

3. INSTALLATION AND REMOVAL TIME

a. LEXINGTON: Installation - 2 - 3 days

Removal - 2 days

b. Escort Ship: Installation - 2 days

Removal - 2 days

V. PERSONNEL

1. TRAINING REQUIREMENTS

None

2. NUMBER AND TYPE OF PERSONNEL

None

VI. CLASSIFICATION AND SECURITY

1. SECURITY MEASURES

None

2. CLASSIFICATION OF PROGRAM

None

3. CLASSIFICATION OF EQUIPMENT

None

4. CLASSIFICATION GUIDE

None

VII. POINTS OF CONTACT

Developing Agency	-	Dr. Gary Trusty, Code 6532 NRL
	-	Dr. Daniel Leslie
		(202) 767-3007 AV. 297-3007
Program Sponsor	-	OP 35 E Service Combat Systems Division
COMOPTEVFOR	-	Code 711 LCDR Paul Vantassel
		AV. 690-5075

FROM: NRL

VIA: CANAVMAT (MAT 08D)

INFORMATION: COMOPTEVFOR DEPCOMOPTEVFOR PAC

COPY TO: CINCLANTFLT

CINCPACFLT

COMNAVAIRLANT

COMNAVSURFLANT

## LEXINGTON SHIP-TO-SHIP TRANSMISSION

### REQUIREMENTS FOR ESCORT SHIP

#### Experimental Equipment Logistics

<u>Location</u>	<u>Space</u>	<u>Equipment</u>	<u>Requirements</u>
Port Bow (far forward)	30-40 ft <sup>2</sup>	For probe mounting: Aerosol probes Air temp, dew point Wind speed, wind direction Nephelometer Mass Monitor	Power required Small tower (we supply) Tie-downs Unobstructed airflow
Anywhere	240 ft <sup>2</sup> (8x30) 14,000 lbs.	Aerosol Van	Tie-downs 110 volts-10 kw
Maindeck Just aft of superstructure	100 ft <sup>2</sup> (10x10) 2000 lbs.	60" Tracker	Clear line-of-sight off port side No personnel traffic in path during operation Tie-downs 110 volts-5 kw Communications to bridge (we can supply)

#### Personnel

Quarters and meals for 3 persons while underway.

#### Ship Operational Requirements

Speed - 32 Knots relative wind speed across deck to keep up with LEXINGTON both during operations and on return to downwind position. Maximum surface speed of LEXINGTON is 27 kts.

Fuel - Must escort LEXINGTON for 2 weeks.

Location - NRL provides position requests (relative to LEXINGTON)

Availability - At berth in Pensacola 2 days prior to experiment for equipment installation. Underway escorting LEXINGTON during experiment (2 weeks). Two days at berth following experiment for equipment removal.

SUMMARY OF NRL-USS LEXINGTON BRIEFING

I. SUBJECT: Ship-to-Ship DF Laser Transmission Experiment

II. ATTENDANCE: NRL LEXINGTON

Dr. Daniel Leslie	CDR Kelley, Operations Officer
Dr. Gary Trusty	CDR Roark, Air Operations
Mr. Tom Cosden	Lt. Burgess, Weather
LTJG Edwin Gaynor	AGCS Koester, Weather
LCDR Stan Grigsby, NAVSEA	

III. DISCUSSION:

1. Presentation

- a. 20 minute VU-Graph Technical Presentation by D. Leslie  
(NRL)

2. Types of Training Aboard LEXINGTON

- a. T-2, T-4A qual. flights, daytime.
- b. A-6, A-7 RAG requal. flights, day time, night-time (CDR Kelley, LEXINGTON)

3. Escort Ship

- a. Availability of reserve destroyer OWENS, due to be decommissioned Dec. 81.
- b. Availability of other appropriate ships in Tampa-St. Petersburg, Pascagoula, and Panama City (CDR Roarke, LEXINGTON).

4. Schedule

- a. LEXINGTON in port the last three weeks of August 82  
Underway first two weeks of Sept. 82 for qual. flights at  
Enclosure (2)



Corpus Christi and RAG requal. flights at Pensacola. Personnel transportation on or off is possible between the two week-long missions.

LEXINGTON will be in the yards October thru November 82, following the underway period in September. LEXINGTON will operate off Key West in December 82.

3. Requirements

- a. A proposal was made to use a small plane for gathering meteorological data along the propagation path for half-hour durations. (Grigsby, NAVSEA) CDR Roarke and CDR Kelley tentatively accented this proposal with several details to be worked out later.

IV. CONCLUSIONS

1. LEXINGTON is able and willing to offer support to NRL in performance of the Ship-to-Ship transmission experiment provided the experiment does not interfere with LEXINGTON's operational objectives.
2. An appropriate time for performing the experiment is during the September 82 underway period.
3. Installation of an air conditioning unit in the forward gun tub will modify near ship turbulence measurements.